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Discovery of the longest-period rapidly oscillating Ap star HD 177765*

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ABSTRACT

We present the discovery of a long-period, rapidly oscillating Ap star, HD 177765. Using high-resolution time-series observations obtained with UVES at the ESO VLT telescope, we found radial velocity variations with amplitudes 7–150 $\mathrm{m\,s^{-1}}$ and a period of 23.6 min, exceeding that of any previously known roAp star. The largest pulsation amplitudes are observed for Eu III, Ce III and for the narrow core of Hα. We derived the atmospheric parameters and chemical composition of HD 177765, showing this star to be similar to other long-period roAp stars. Comparison with theoretical pulsational models indicates an advanced evolutionary state for HD 177765. Abundance analyses of this and other roAp stars suggest a systematic variation with age of the rare-earth line anomalies seen in cool Ap stars.

Key words: stars: chemically peculiar – stars: magnetic fields – stars: oscillations – stars: individual: HD 177765

1 INTRODUCTION

The rapidly oscillating (roAp) stars are magnetic, chemically peculiar stars which pulsate in high-overtone acoustic modes with typical periods of ≈ 10 min. These stars are located close to the instability strip crossing the main sequence between the early F and late A spectral types. First roAp pulsators were discovered by Kurtz (1982). Currently, about 40 of such stars are known.

Several excitation mechanisms were suggested in the past to drive pulsations in roAp stars (Dolez et al. 1988; Dziembowski 1984; Shibahashi 1983; Matthews 1988). Currently, it is widely accepted that the high frequency oscillations observed in these stars are excited by the opacity mechanism working on the hydrogen ionization region. However, full non-adiabatic calculations show that the excitation of high frequency acoustic oscillations by this mechanism can only be achieved in non-standard models, such as models with a modified T-tau relation (Gautschy et al. 1998), or models with envelope convection partially or fully suppressed (Balmforth et al. 2001; Saio 2005).Among these, models with convection suppressed seem to reproduce better the observed instability strip, however, the predicted red edge remains significantly hotter than the observed one.

The majority of roAp stars have been identified and analysed using high-speed photometric methods (Kurtz & Martinez 2000). However, it has been realised that the ground-based photometry is not particularly suitable for discovering roAp stars. Time-resolved spectroscopy has a major advantage for detection of smaller-amplitude and longer-period pulsations. This has been demonstrated by, for example, the discovery of very low-amplitude pulsations in HD 75445 (Kochukhov et al. 2009) and by the detection of long-period oscillations in HD 137909 (β CrB, Hatzes & Mkrtichian 2004) and HD 116114 (Elkin et al. 2005), which have been repeatedly classified as non-pulsating by photometric observations (Martinez & Kurtz 1994; Lorenz et al. 2005).

The two latter objects, along with a faint roAp star KIC 10195926 found by the Kepler satellite (Kurtz et al. 2011), form an unusual sub-group with pulsation periods of 16–21 min and spectroscopic properties different from the "classical", shorter-period roAp stars. Here we present the spectroscopic discovery of another member of this class, HD 177765, whose pulsation period of 24 min is the longest known for any roAp star.

2 OBSERVATIONS AND DATA REDUCTION

Time-resolved spectroscopic observations of HD 177765 were carried out on 12 June 2010, using the Ultraviolet and Visual Echelle Spectrograph (UVES) at one of the 8.2-m UTs of the ESO Very Large Telescope. We obtained 50 spectra during a 66-min observing period, which started at HJD=2455359.8087 and finished at HJD=2455359.8547. The spectrograph was used in the 600 nm red-arm setting with an image slicer. This configuration provided

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a resolving power of $R \approx 110,000$ and complete wavelength coverage of the 4980–7010 Å region with the exception of a 65 Å-wide gap at $\lambda \approx 5990$ Å.

We used 60 s exposure times for individual observations. The employed ultra-fast (4-port, 625 kpix s^{-1}) readout mode of the UVES CCDs allowed to reduce the overhead to 21 s, giving a time resolution of 81 s. The typical signal-to-noise ratio (S/N) of individual spectra was 80-95 in the 5000–5500 Å region. The stellar observations were followed by a single ThAr calibration exposure. In addition, bias and flat-field images were obtained as part of the standard daytime calibration of UVES.

Reduction of the spectra was perform with a new version of our UVES pipeline, described by Lyashko et al. (2007) and used in our previous studies of roAp stars (Kochukhov et al. 2007; Ryabchikova et al. 2007a). This code takes care of the standard spectra processing and calibration operations: bias averaging and subtraction, determination of the echelle order positions, subtraction of the scattered light, extraction of 1-D stellar spectra, pixel-to-pixel sensitivity and blaze function correction using flat-field. Compared to the previous version of the code, we introduced a new procedure for the determination of the order boundaries and improved the calculation of the heliocentric Julian date and barycentric radial velocity correction.

In the last step, we determined the dispersion solution with a precision of 35–40 m s^{-1} using ThAr emission spectrum taken after the stellar time-series and performed the final continuum normalization. The latter was carried out in two steps. First, we produced a high-quality average spectrum and determined the continuum level by fitting a spline function to manually selected points. Second, we re-normalized automatically each individual spectrum to match the continuum of the average observation.

3 THE PROPERTIES OF HD 177765

Little was known about HD 177765 before our study. This star, classified as A5 SrEuCr (Renson & Manfroid 2009), was observed by Martinez & Kurtz (1994), who did not detect pulsations from the photometric observations on two nights. Mathys et al. (1996) estimated $T_{\rm eff}$ = 8060 K, while Mathys et al. (1997) detected magnetic field from the Zeeman split line Fe II λ 6149.2 Å. According to that study, the mean field modulus of HD 177765 remained constant at $\langle B \rangle$ = 3.4 kG with a scatter of 20 G during about 2 years covered by their observations, suggesting a very long rotational period.

We used TEMPLOGG$^{\rm TNG}$ code (Kaiser 2006) to determine atmospheric parameters of HD 177765 from photometry. Using the Strömgren photometric indices $(b-y)$ = 0.248, m_1 = 0.261, c_1 = 0.731, Hβ = 2.834 reported by Martinez (1993), we obtained $T_{\rm eff}$ = 8050 K, $\log g$ = 4.3 with the calibration by Moon & Dworetsky (1985) and $T_{\rm eff}$ = 7900 K, $\log g$ = 4.6 with the calibration by Napiwotzki et al. (1993). Simultaneously, we estimated the reddening $E(b-y)$ = 0.104 and metallicity [M/H]=+0.9. This interstellar reddening was applied to the Geneva photometric data[1]. The dereddened $(B2-G)_0 = -0.404$ index yields $T_{\rm eff}$ = 7750 K according to the calibration by Netopil et al. (2008).

Taking into account the high metallicity estimated from the Strömgren photometry and the similarity of the mean abundances of HD 177765 and of the roAp star β CrB (see Sect. 5), we calculated a set of models around $T_{\rm eff}$ = 8000 K and $\log g$=3.5–4.0 with

[1] http://obswww.unige.ch/gcpd/ph13.html

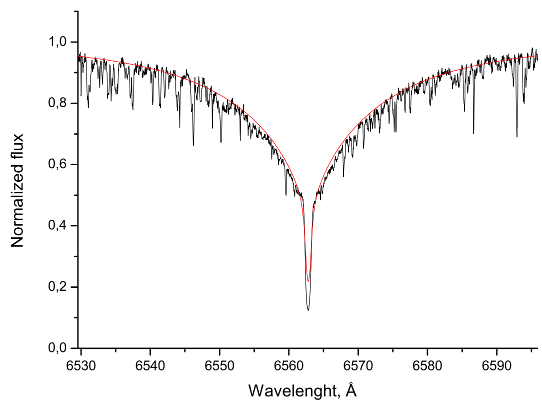

Figure 1. Observed Hα profile (black line) and synthetic spectrum (red line) calculated for $T_{\rm eff}$ = 8000 K and $\log g$ = 3.8.

the β CrB abundances using the LLMODELS model atmosphere code (Shulyak et al. 2004). The final atmospheric parameters of HD 177765 were obtained by fitting the observed Hα profile to the synthetic spectra calculated using the SYNTHV code (Tsymbal 1996). The best fit, corresponding to $T_{\rm eff}$ = 8000 K and $\log g$ = 3.8, is illustrated in Fig. 1.

We estimated the mean magnetic field modulus $\langle B \rangle$ = 3550 G from the separation of the Fe II λ 6149.26 Å Zeeman components in the average UVES spectrum. This measurement is significantly higher than the value reported by Mathys et al. (1997). We also used magnetic spectrum synthesis code SYNTHMAG (Kochukhov 2007) to model partially resolved lines of different chemical elements. This analysis showed that a different field orientation is needed to fit the spectral lines of Fe-peak and rare-earth (REE) elements. To reproduce the latter, the field lines must be oriented predominantly parallel to the stellar surface, while the former lines require a significant radial field contribution. This difference may be related to inhomogeneous horizontal abundance distributions.

Due to the combined effect of magnetic field and chemical stratification it is difficult to derive an accurate projected rotational velocity for HD 177765. The commonly used magnetically insensitive Fe I λ 5434.52 Å line is too strong and is broadened due to a vertical abundance stratification. We estimated the total broadening to be equivalent to $v_{\rm e} \sin i$ = 2.2–2.7 km s^{-1} from the spectrum synthesis fit to a much weaker magnetically insensitive Fe II λ 6586.7 Å line and to the partially resolved Zeeman components of several other weak lines. In roAp stars this broadening is not necessarily due to stellar rotation alone (Kochukhov & Ryabchikova 2001; Ryabchikova et al. 2007a).

4 RADIAL VELOCITY ANALYSIS

Initial analysis of the radial velocity (RV) data revealed variations in the core of Hα with a period >20 min and suggested the presence of a marginal variability in many individual lines, especially those belonging to heavy elements. To obtain precise measurements, we combined RVs derived for all unblended lines of a given ion using the centre-of-gravity method (Kochukhov & Ryabchikova 2001). Spectral lines were identified using information from the VALD data base (Kupka et al. 1999) and identification lists of variable lines compiled for other roAp stars (e.g., Ryabchikova et al. 2007b).

Our frequency analysis consisted of the following steps. After obtaining mean RV measurements for each ion, we calculated

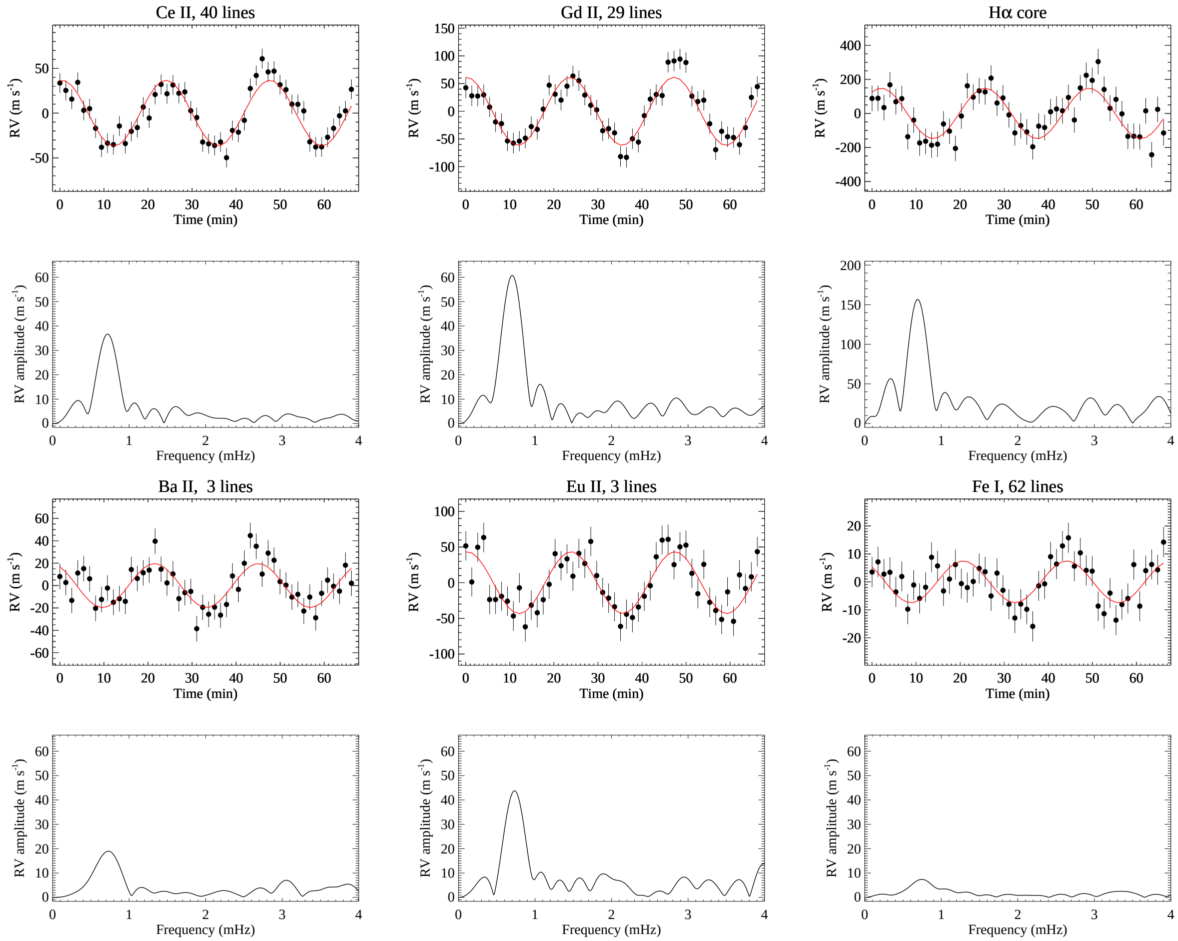

Figure 2. Radial velocity variation and amplitude spectra for Ce II, Gd II, Hα core, Ba II, Eu II, and Fe I. Each panel shows the radial velocity curve on top, comparing the least-squares cosine fit (solid line) with observations (symbols). The corresponding amplitude spectra are presented below.

the corresponding amplitude spectra using discrete Fourier transform and estimated an initial value for the pulsation period from the highest amplitude peak. We also computed a periodogram as described by Horne & Baliunas (1986) in order to assess the False Alarm Probability (FAP) of the signal detection. Then we applied a non-linear least-squares fitting procedure to improve the period and estimate an amplitude and phase of the RV variations.

This analysis clearly showed the presence of pulsation variability (FAP $< 10^{-5}$) in the core of Hα and in the lines of Eu II, Gd II, and Ce II. The RV amplitude reaches 150 m s^{-1} for Hα, but it is only 40–60 m s^{-1} for the three rare-earth ions. These four elements show periods of 22.85 ± 0.39 min (Eu), 23.50 ± 0.26 min (Ce), 23.85 ± 0.27 min (Gd), and 24.05 ± 0.51 min (Hα), yielding a weighted mean pulsation period of 23.56 ± 0.16 min or a mean frequency of $\nu = 0.707 \pm 0.005$ mHz, which is the lowest frequency detected in a roAp star. This period was adopted in the subsequent linear least-squares analysis of the remaining elements.

Several other ions show a probable ($10^{-5} < \mathrm{FAP} < 10^{-3}$) variation in the period range of 23–24 min with amplitudes of 10–130 m s^{-1}. A single line of Eu III shows the highest amplitude among metal lines. We also detected variability in the lines of Ba II, Yb II, and somewhat unexpectedly, Fe I. Combining information from 62 lines of the neutral iron, we were able to detect the pulsation amplitude of 7.4 ± 1.1 m s^{-1}. At the same time, the RV curve constructed from 21 lines of ionized iron does not show any variation. Phase shifts of ~ 0.1 of the pulsation period inferred from the RV curves of different ions probably reflect the difference in their formation heights.

Many roAp stars show large-amplitude pulsations in the lines of singly and doubly ionized Nd and Pr (Ryabchikova et al. 2007a). Nd III and Pr III lines are relatively weak and heavily blended in the spectrum of HD 177765, unlike in typical roAp stars where these lines are among the strongest metal spectral features (Ryabchikova et al. 2004). Neither singly nor doubly ionized lines of Pr and Nd provide precise RVs for HD 177765 due to blending by iron peak elements. Our results indicate the absence of pulsation variability in the blends containing contributions by these ions with upper limits of $\approx$ 15–20 m s^{-1}. We also did not detect variability in the lines of Ca I/ II, La II, Cr I/ II, and Y II. A marginal signal at the right frequency may be present in the lines of neutral and ionized Ti.

Representative RV curves and amplitude spectra are shown in Fig. 2. The outcome of the linear least-squares fit with a fixed pulsation period is reported in Table 1 for all measured elements. This Table also gives the FAP information.

The short duration of our monitoring of HD 177765 allowed to cover only 3 pulsation cycles. These observational data are insufficient to perform a very precise frequency analysis and assess possible presence of other frequencies. However, we note a systematic deviation of the mean RV curves of Ce II, Gd II, and Hα

Table 1. Results of the time-series analysis of different ions in the spectrum of HD 177765. The columns give the element and ionization stage, the number of spectral lines used to construct average radial velocity curves, the amplitude A and phase φ derived in the least-squares cosine fit, where φ is given as a fraction of the pulsation period $P = 23.56$ min. The last column indicates a False Alarm Probability (FAP) for the highest peak in the corresponding amplitude spectra.

Ion	N	A ($\mathrm{m\,s^{-1}}$)	φ	FAP
Gd II	29	61.4±3.7	0.99±0.01	2.7e-8
Ce II	40	36.7±2.2	0.98±0.01	2.6e-8
Hα	1	148.0±14.8	0.91±0.02	2.1e-7
Eu II	3	43.3±4.1	0.99±0.02	8.7e-7
Ba II	3	19.6±2.3	0.08±0.02	1.7e-5
Yb II	3	31.3±4.3	0.01±0.02	1.2e-4
Fe I	62	7.4±1.1	0.12±0.02	1.7e-4
Ce III	2	65.0±12.1	0.88±0.03	2.8e-4
Ti I+Ti II	12	8.8±1.7	0.06±0.03	5.3e-3
Eu III	1	128.8±28.5	0.06±0.03	3.0e-2
Ca I+Ca II	10	4.2±2.0	0.01±0.07	9.0e-2
Fe II	21	3.8±1.7	0.10±0.07	2.5e-1
La II	13	13.7±9.0	0.01±0.10	7.4e-1
Cr I+Cr II	12	7.1±2.2	0.19±0.05	3.4e-1
Y II	9	11.0±5.1	0.30±0.08	6.3e-1
Pr III	2	23.5±7.6	0.26±0.26	6.6e-1

core from the mono-periodic least-squares solution (see upper row in Fig. 2). All three elements show a somewhat higher amplitude in the second half of the time-series, which indicates the presence of additional pulsation frequencies.

5 ABUNDANCE ANALYSIS

We derived preliminary abundance estimates for HD 177765 from equivalent widths using a modified version of WIDTH9 code (WIDTHMF) written by V. Tsymbal, where magnetic intensification effects are taken into account via the magnetic pseudo-microturbulence. We checked that this procedure works well for Fe, yielding a reasonable agreement with detailed magnetic spectrum synthesis calculations. For instance, fitting 18 Fe I and 33 Fe II lines with SYNTHMAG we obtained $\log(N_{\mathrm{Fe}}/N_{\mathrm{tot}}) = -3.40 \pm 0.22$ for Fe I and $\log(N_{\mathrm{Fe}}/N_{\mathrm{tot}}) = -3.25 \pm 0.32$ for Fe II. The corresponding abundances retrieved with WIDTHMF are -3.65 ± 0.33 and -3.40 ± 0.40. The systematic difference in abundances is well within the errors, which are rather large.

An inspection of individual Fe II lines reveals a strong dependence of the abundance on the line transition probability and on the excitation energy of the lower level. We interpret this as an evidence for vertical chemical stratification, which is a common phenomenon for Ap stars. A detailed stratification analysis of HD 177765 is beyond the scope of our study.

Atomic parameters for abundance determination were taken from VALD and from the DREAM database for REEs (Biémont et al. 1999) using the VALD extraction tools. For Fe II lines a preference was given to the homogeneous set of calculations by Raassen & Uylings (1998), supplemented by the data from Castelli & Kurucz (2010) for newly identified high excitation lines. The europium abundance was derived from Eu II lines by comparison with synthetic spectra taking magnetic field effects, isotopic and hyperfine splitting into account. The corresponding data were extracted from Lawler et al. (2001). The parameters of the Eu III λ 6666.35 Å line were adopted from Wyart et al. (2008).

Table 2. Chemical composition of HD 177765. The error estimates are based on standard deviation of abundances estimated from N lines. The last column gives the abundances for β CrB from Ryabchikova et al. (2004), except for Ce III and Eu III which were determined here.

Ion	$\log(N_{\mathrm{el}}/N_{\mathrm{tot}})$	N	β CrB
C I	-3.70	1	
Si I	-3.63 ± 0.23	3	
Si II	-3.56	1	-4.09
Ca I	-4.64 ± 0.43	6	-5.10
Ca II	-4.22	1	
Ti I	-5.94 ± 0.24	2	-6.15
Ti II	-6.48 ± 0.19	6	-5.86
Cr I	-4.18 ± 0.51	10	-4.60
Cr II	-4.36 ± 0.35	24	-4.68
Mn I	-5.07 ± 0.04	3	
Mn II	-5.30	1	-5.02
Fe I	-3.40 ± 0.22	18	-3.92
Fe II	-3.25 ± 0.32	23	-3.66
Co I	-5.06 ± 0.43	4	
Ni I	-6.35 ± 0.27	3	-5.41
Sr I	-5.47 ± 0.05	2	
Y II	-8.44	1	
Zr II	-8.38	1	-8.39
La II	-8.60 ± 0.44	3	-8.35
Ce II	-7.01 ± 0.36	72	-7.84
Ce III	-5.49 ± 0.09	4	-5.65
Pr II	-9.54	1	-9.26
Pr III	-8.69	1	-9.35
Nd II	-9.40 ± 0.22	2	-9.17
Nd III	-8.53 ± 0.10	3	-8.36
Eu II	-7.95 ± 0.13	3	-8.28
Eu III	-6.20	1	-5.65
Gd II	-7.62 ± 0.29	7	-7.54
Dy II	-6.90	1	
Yb II	-7.99 ± 0.31	6	

Our abundance estimates for HD 177765 are given in Table 2. The last column of this table compares the chemical composition of HD 177765 with the elemental abundances in the atmosphere of the roAp star β CrB determined by Ryabchikova et al. (2004). These authors did not provide Ce III and Eu III abundances, therefore we have estimated them using the same model atmosphere and the same observations as in Ryabchikova et al. (2004). The similarity of the chemical composition of the two stars is clearly evident. Neither of these stars shows the 1.5–2.0 dex difference between abundances derived from Pr and Nd lines in the first and second ionization stages, which is typical of most roAp stars (Ryabchikova et al. 2004). But they exhibit a pronounced CeEu ionization anomaly. Both β CrB and HD 177765 have longer pulsation periods than the stars with the PrNd anomaly.

6 CONCLUSIONS AND DISCUSSION

We have analysed time-resolved spectra of the cool Ap star HD 177765 obtained with the UVES instrument at VLT. The radial velocity and frequency analysis of these data reveals this object to be a roAp star with the pulsation period of 23.6 min. These oscillations, clearly present with amplitudes 40–150 $\mathrm{m\,s^{-1}}$ in the com-

bined radial velocity curves of Ce II, Eu II and Gd II lines, as well in the Hα core, occur with the longest known pulsational period for any roAp star. This discovery makes HD 177765 a key object for testing predictions of pulsation theories because the frequency limits help in distinguishing alternative driving mechanisms and can provide useful asteroseismic constraints on the atmospheric and interior stellar structure.

No trigonometric parallax measurement is availble for HD 177765. Therefore, we can only approximately place it in the HR-diagram for a comparison with pulsational models. Using the effective temperature, derived from photometry and spectroscopy, the pulsation frequency $\nu = 0.7$ mHz, and the evolutionary tracks from Cunha (2002), which provide the frequency of the most unstable mode for models with given effective temperature and luminosity, we obtain a mass $M \approx 2.2 M_{\odot}$ and a luminosity $\log L/L_{\odot} \approx 1.5$. These parameters imply that the star is significantly evolved from the zero age main sequence, making it similar to the three other long-period, evolved roAp stars: β CrB, HD 116114, and KIC 10195926.

We have carried out an abundance analysis of HD 177765 using the equivalent width and spectrum synthesis methods. A slow variation of the mean field modulus suggests a long rotational period. The diversity of Zeeman splitting patterns and the dependence of the abundance on the line strength and excitation potential (most clearly seen for Fe) indicates strong horizontal and vertical inhomogeneities.

We found that HD 177765 is chemically similar to β CrB. Both stars are distinguished by a high Ce abundance and discordant abundances inferred from different ions of Eu and Ce. But both stars lack a strong PrNd ionisation anomaly which is characteristic of higher frequency roAp stars. This anomaly is also absent in HD 116114. Thus, instead of being a spectroscopic signature of roAp stars as suggested by Ryabchikova et al. (2004), the PrNd anomaly is probably related to the evolutionary state of roAp stars, distinguishing evolved, long-period pulsators from the shorter-period stars closer to the zero age main sequence. This finding represents one of the most compelling evidence for a systematic variation of surface chemical composition of Ap stars with age.

Longer time-series observations of HD 177765 are highly desirable to determine additional pulsation frequencies which are necessary for an astroseismic analysis. Observations during a single night might be sufficient to resolve the expected large frequency separation of $\Delta\nu_0 \sim 50$ μHz.

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REFERENCES

Balmforth N. J., Cunha M. S., Dolez N., Gough D. O., Vauclair S., 2001, MNRAS, 323, 362
Biémont E., Palmeri P., Quinet P., 1999, Ap&SS, 269, 635
Castelli F., Kurucz R. L., 2010, A&A, 520, A57
Cunha M. S., 2002, MNRAS, 333, 47
Dolez N., Gough D. O., Vauclair S., 1988, in Christensen-Dalsgaard J., Frandsen S., eds., IAU Symp. 123, Advances in Helio- and Asteroseismology. D. Reidel Publishing Co., Dordrecht, p. 291
Dziembowski W., 1984, in Noels A., Gabriel M., eds., 25th Liege International Astrophysical Colloquium, Theoretical Problems in Stellar Stability and Oscillations. Université de Liège, p. 346
Elkin V. G., Riley J. D., Cunha M. S., Kurtz D. W., Mathys G., 2005, MNRAS, 358, 665
Gautschy A., Saio H., Harzenmoser H., 1998, MNRAS, 301, 31
Hatzes A. P., Mkrtichian D. E., 2004, MNRAS, 351, 663
Horne J. H., Baliunas S. L., 1986, ApJ, 302, 757
Kaiser A., 2006, in Aerts C., Sterken C., eds., ASP Conf. Ser. Vol. 349, Astrophysics of Variable Stars. Astron. Soc. Pac., San Francisco, p. 257
Kochukhov O., Bagnulo S., Lo Curto G., Ryabchikova T., 2009, A&A, 493, L45
Kochukhov O., Ryabchikova T., 2001, A&A, 374, 615
Kochukhov O., Ryabchikova T., Weiss W. W., Landstreet J. D., Lyashko D., 2007, MNRAS, 376, 651
Kochukhov O. P., 2007, in Romanyuk I.I., Kudryavtsev D.O., eds., Physics of Magnetic Stars. SAO RAS, Niznij Arkhyz, p. 109
Kupka F., Piskunov N., Ryabchikova T. A., Stempels H. C., Weiss W. W., 1999, A&AS, 138, 119
Kurtz D. W., 1982, MNRAS, 200, 807
Kurtz D. W. et al., 2011, MNRAS, 414, 2550
Kurtz D. W., Martinez P., 2000, Baltic Astronomy, 9, 253
Lawler J. E., Wickliffe M. E., den Hartog E. A., Sneden C., 2001, ApJ, 563, 1075
Lorenz D., Handler G., Kurtz D. W., 2005, Information Bulletin on Variable Stars, 5651, 1
Lyashko D. A., Tsymbal V. V., Makaganiuk V. A., 2007, in Mashonkina L., Sachkov M., eds., Spectroscopic methods in modern astrophysics. Moscow, p. 100
Martinez P., 1993, PhD thesis, University of Cape Town
Martinez P., Kurtz D. W., 1994, MNRAS, 271, 129
Mathys G., Hubrig S., Landstreet J. D., Lanz T., Manfroid J., 1997, A&AS, 123, 353
Mathys G., Kharchenko N., Hubrig S., 1996, A&A, 311, 901
Matthews J. M., 1988, MNRAS, 235, 7P
Moon T. T., Dworetsky M. M., 1985, MNRAS, 217, 305
Napiwotzki R., Schoenberner D., Wenske V., 1993, A&A, 268, 653
Netopil M., Paunzen E., Maitzen H. M., North P., Hubrig S., 2008, A&A, 491, 545
Raassen A. J. J., Uylings P. H. M., 1998, A&A, 340, 300
Renson P., Manfroid J., 2009, A&A, 498, 961
Ryabchikova T., Nesvacil N., Weiss W. W., Kochukhov O., Stütz C., 2004, A&A, 423, 705
Ryabchikova T., Sachkov M., Kochukhov O., Lyashko D., 2007a, A&A, 473, 907
Ryabchikova T. et al., 2007b, A&A, 462, 1103
Saio H., 2005, MNRAS, 360, 1022
Shibahashi H., 1983, ApJ, 275, L5
Shulyak D., Tsymbal V., Ryabchikova T., Stütz C., Weiss W. W., 2004, A&A, 428, 993
Tsymbal V., 1996, in Adelman S.J., Kupka F., Weiss W.W., eds., ASP. Conf. Ser. Vol. 108, Model Atmospheres and Spectrum Synthesis. Astron. Soc. Pac., San Francisco, p. 198

Wyart J.-F., Tchang-Brillet W.-Ü. L., Churilov S. S., Ryabtsev A. N., 2008, A&A, 483, 339